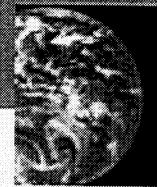




The Finer Details

Climate
modeling
techniques
can increase
accuracy and
speed up
processing time



If you want to know whether you will need sunscreen or an umbrella for tomorrow's picnic, you can simply read the local weather report.

However, if you are calculating the impact of gas combustion on global temperatures, or anticipating next year's rainfall levels to set water conservation policy, you must conduct a more comprehensive investigation. Such complex matters require long-range modeling techniques that predict broad trends in climate development rather than day-to-day details.

Climate models are built from equations that calculate the progression of weather-related conditions over time. Based on the laws of physics, climate model equations have been developed to predict a number of environmental factors, for example:

- Amount of solar radiation that hits the Earth
- Varying proportions of gases that make up the air
- Temperature at the Earth's surface
- Circulation of ocean and wind currents
- Development of cloud cover

Efficient and accurate climate modeling requires powerful computers that can process billions of mathematical calculations in a single second.

Numerical modeling of the climate can improve our understanding of both the past and the future. A model can confirm the accuracy of environmental measurements taken in the past and can even fill in gaps in those records. In addition, by quantifying the relationship between different aspects of climate, scientists can estimate how a future change in one aspect may alter the rest of the world. For

example, could an increase in the temperature of the Pacific Ocean somehow set off a drought on the other side of the world? A computer simulation could lead to an answer for this and other questions.

Quantifying the chaotic, nonlinear activities that shape our climate is no easy matter. You cannot run these simulations on your desktop computer and expect results by the time you have finished checking your morning e-mail. Efficient and accurate climate modeling requires powerful computers that can process billions of mathematical calculations in a single second. The NCCS exists to provide this degree of vast computing capability.

The challenge of accuracy

Why does a climate model need so much processing power? The answer lies not only in the sheer complexity of the equations but also in the

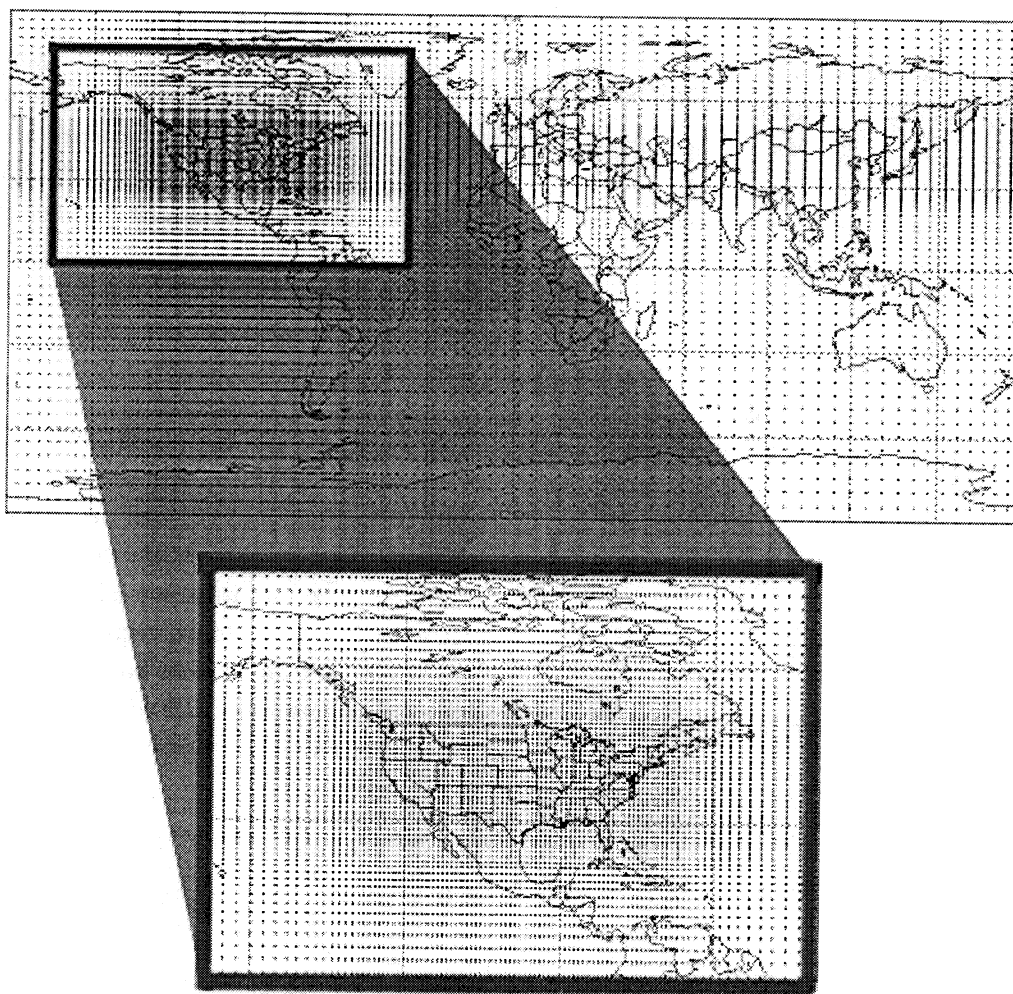


Climate Modeling

number of times that the equations are performed to produce results that are as accurate as possible.

First, the model calculates each equation for numerous points throughout the physical area

that it is designed to cover. An investigator defines a three-dimensional area in a grid of points for the physical space that the climate model will cover. The grid is divided into layers for various altitudes within its vertical scale. It may cover an altitude as high as 60 kilometers



A stretched grid concentrates a climate model's calculation points in a specific area, reducing the amount of computation time spent outside that area. *Image credit: Michael Fox-Rabinovitz, NASA Goddard Space Flight Center, Data Assimilation Office*



Regional Modeling

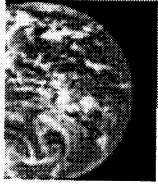
Sometimes, a researcher wants to focus on a particular region, but a high-resolution global climate model would require extensive work for areas in which the researcher is not necessarily interested. If researchers could reduce or even eliminate this extra work, they could use the processing time they saved to increase the resolution for the area of interest.

Would it be possible to calculate only for the selected region and cut out the rest of the model? Perhaps, but doing so would ignore the interconnected nature of the world-wide global climate system. Therefore, the goal is to reduce unneeded processing and still record the influence of the entire environment on the selected region.

A nested grid can accomplish this goal. A *nested grid* is a low-resolution global model that contains another smaller, high-resolution grid. At each time step, the computer calculates first for the global grid. Because its resolution is low, it runs relatively quickly and provides just enough data to initialize the high-resolution grid that covers the smaller focus area.

One problem with the nested grid approach is that the connection between the two grids is not always perfect. Because of the difference in resolution, inaccuracies in the results, or *noise*, may result for the boundary layer where the grids meet. The noise can be "turned down" by adding special formulae, or *boundary schemes*, to the model equations. These schemes are designed to ease the sharp differences that may appear between grids that are drastically different in resolution.

On the other hand, a variable-resolution model does not require boundary schemes because it contains only a single stretched grid. Many of the calculation points are concentrated in a selected area, and the remaining points are stretched over the rest of the globe. This distribution reduces resolution and, thus, computing time for areas in which fine climate details are not required.



and divide the distance over dozens of *strata*, or layers.

Each level in the vertical scale contains points that vary in location by 1 to 3 degrees in latitude and longitude. The *resolution*, or number of calculation points, determines a model's accuracy. If the resolution is too low, some factors that influence the climate, such as cloud cover, may slip through the grid points and not be taken into account.

Researchers can increase the accuracy of a model by coupling it with models of other climate factors. This process employs algorithms to use one model's calculations as input to another model. A coupled climate model is more accurate because it takes into account the interrelated nature of our environment. For instance, warm sea surface temperatures (SSTs) can heat low-lying air and strengthen the flow of nearby wind currents. Depending on the extra models, coupling additional climate components may

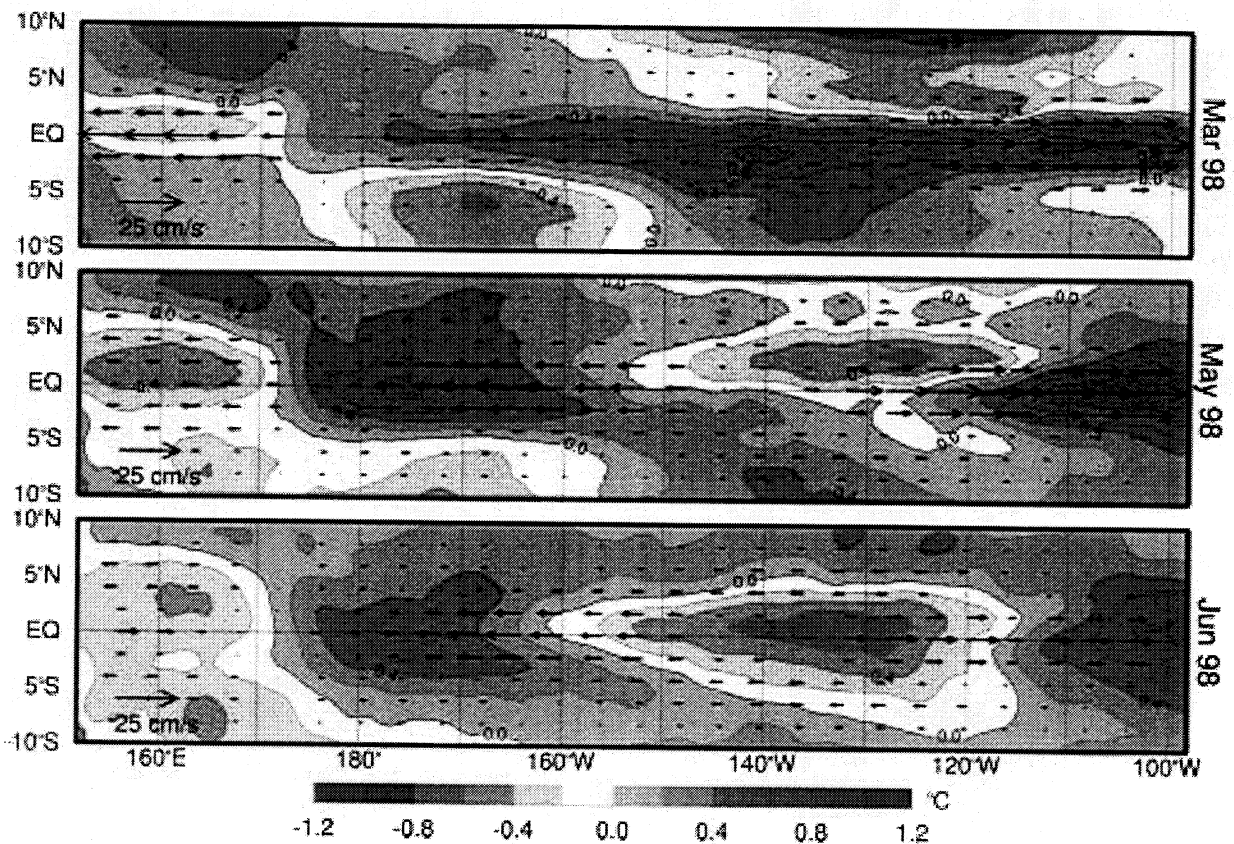
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increase the computational load by up to 10 times.

Data assimilation is another modeling task that typically requires powerful mathematical calculating capability. Assimilation entails the periodic input of observed climate measurement values into a simulation.

Recordings such as SSTs taken on boats and remote sensing data from satellite readings can be assimilated into a climate model. The measurements provide a reality check for the simulation, and the new calculations can fill in any missing spots in the measurement data set.

Obtaining a reliable climate solution at any particular moment in time may require many thousands of calculations, and that is only the beginning. Results are generated for numerous time steps in a single run that can cover decades of time. Furthermore, an investigator will often repeat the entire run multiple times to verify the results.



A major challenge in studying climate progression is making sense of huge amounts of observational data. Through a complex series of mathematical operations known as a *multivariate empirical orthogonal function* (MEOF) analysis, major patterns of variation in the data can be isolated. This graph shows MEOF results for the movement of equatorial currents and ocean temperature changes during the 1998 La Niña phenomenon. Image credit: University of Maryland, Earth System Science Interdisciplinary Center (ESSIC)